

# CODYBA, A DESIGN TOOL FOR BUILDINGS PERFORMANCE SIMULATION

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## ABSTRACT

CODYBA is a software addressed to designers, teachers and research organisms. This software determines the energetic fluxes of a building zone. The basic data are the zones geometry and constitution. The main parameters are the climatic conditions, the internal loads and the heating and air conditioning powers, as well as their regulation mode. The graphical interface introduces concepts that are identical to those manipulated in the everyday practice by the building professionals and that are reproduced on screen by a classic "iconographical" representation in the "Windows" environment.

## INTRODUCTION

The thermal behaviour of buildings, considered as a "thermal system", has been the object of numerous software developments in past 30 years. Most of them are the result of institutional research programs (TRNSYS [1], CLIM2000 [2], etc.). In order to allow a wider diffusion, an interface has been added to these simulation codes. Most of this programs has poor ergonomic qualities precisely because of this "addition" to the primary product. CODYBA has been developed by the CETHIL team since 1981, first as a thesis result and a commercial version exist since 1985 [3]. Until version number 5 this is the way CODYBA has been developed.

Knowing that version 5 was to be reconsidered, it was decided to redesign the software completely. Considering the fact that the algorithms of version 5 were validated [3], essential efforts could be devoted to the definition of the best way of communication of the specialist domain and the software itself.

In other words, the steps of design were reversed. It is the ergonomics that decides the way to organize the means of calculations.

This article describes the sequence of the stages leading to the construction of the software: the V lifecycle ([4], p 168) has been adopted to elaborate the new version. In fact, it is rather the "spiral lifecycle" ([4], p 161) which was followed, once it is more adapted to the scientific field.

First, the constraints of the initial specifications will be pointed out, which expresses waitings of users, perceived through out the experience feedbacks of version 5.

Then the adopted modelings to answer these constraints will be present. The main difficulty was the decomposition of a building in elementary objects having all at the same time a physical, equationnal and data-processing existence.

Finally, some screen hard copies will be present to make more visual the adopted solutions.

In conclusion, the current state of development of the software will be evoke, and the improvements which will be carried out in the near future.

## THE AIM OF THIS NEW VERSION

CODYBA version 6 most important aim is to offer to heat engineers or technicians a prevision tool permitting to establish accurate energy balance or to analyse the influence of certain parameters like, for example, control, windows, solar protections, building inertia or orientations, etc.. This simulation tool should be simple, accessible, reliable, robust and evolutionary.

The next objective is to give a fine tool for analysis to the scientist domain of building physics. In order to do so and in a long term perspective, the module of calculation must authorize calculations covering most of thermal problems encountered in buildings.

The various stages of this software creation are: review of the equation sets, specifications, general and detailed design, validation and release of the software.

## SET OF PHYSICAL EQUATIONS

The physical equations are those classically adopted for the thermal balance of a room [5]. Classical hypothesis are used:

Air volume representation: a single set of variable (one air temperature, one average radiant temperature, one specific moisture ratio) for each room or group of rooms.

One dimension conduction: a simplified model is implemented for each wall [3].

Solar fluxes: calculated at each time step, on external surfaces, through the windows (solar patch is supposed to reach the floor and is distributed with diffuse multi-reflexions).

## SPECIFICATIONS

The aim is to formalize users requirements and to express a demand:

1 Transparency of the models: for a given physical phenomenon different models must be able to be used, like conduction in the wall by one of the simplified models of Laret [6], by a state reduced order model [7], by finite volume technique, etc.. The choice of the model must be automatic for "standard users", and kept free for the specialists (expert or scientific).

2 Robustness of the numerical algorithms: they must always give a "good" solution in a defined time, or to generate an exploitable error.

3 Verifiability: the software architecture must make it possible to carry out recurring tests, and the software must comprise internal procedures of errors searching.

4 Extensibility: the number of objects of the software should not be limited, and one must thus be able to pile up an unspecified number without degrading of it the performances of resolution.

5 Development staff: limited, concentrating efforts on the strong points of the development team.

6 Evolutionarity: the architecture must allow a re-use of the data-processing sources without modification of the existing modules (pyramidal construction).

7 Exhaustivity: in a long term, cover all the field of building physics applications, for an unspecified size of building, in various aspects (thermal bridges, ventilation, etc.).

8 Language: translation of the on line help and of all the menu and then become a multi-language software (menus are actually available in french, english and brazilian portuguese).

## ANALYSIS

The purpose of the analysis phase is to define what is to be developed: one attaches each analysis point to certain specifications.

Translation of the physical models by objects having at the same time data and numerical methods of resolution adapted to the equations that are used (items 1, 3 and 6).

Opening of the software in the field of "models integration", but the insertion of new models in CODYBA must be a task for an expert. That guarantees for example its performances and prevents from the introduction of heterogeneous models, for example having very different time characteristic (items 2, 3, 6 and 7).

Use of many commercial products, what implies to well partition the data entry, models, calculation and program outputs (items 5 and 6).

Matrix systems resolution by iterative methods on a not assembled system, in order to avoid size limitations of matrix systems and to quickly obtain a solution starting from an initial condition close to convergence point (item 4).

Object-oriented design [4] is based on the maximum atomization of the physical entities and the basic "bricks" of modeling (items 3 and 6).

C++ development: this makes possible an object-oriented design, the integration of "free" C modules (available on Internet), links with many commercial tools, etc.. And at least and very useful, the C++ compilers are robust and very sophisticated concerning the detection and debugging of errors (items 2, 3 and 5).

Graphic Interface: reduced to a minimum number of screens, seeking a maximum factorization of the functionalities of data entry (item 5).

## PRELIMINARY DESIGN

The energy conservation for a given volume is the basic equation. It's integration, limited to a volume with uniform properties, is:

$$\rho.C.Volume.\frac{dT}{dt} = \sum Surfaces Flux + \sum Voluminal Flux$$

The adopted modeling consists in representing the volumes by nodes of a graph and the fluxes by its arcs. In reality, the voluminal fluxes are linked to only one volume. To generalise, the involved energy comes from a specific volume that is called "exterior". In this way, there are always two nodes to each arc.

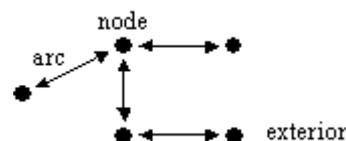


Figure 1: Nodes and Arcs

The adopted modeling consists in reducing it to a "valued" graph. This modeling is not new, it has already been used under the form of "capacity-conductance" in the domain of building physics. Our originality is that its logic is simply "push" the its limits, generalising this modeling to the whole building and to its climatic environment. Doing this, arcs and the nodes are the only entities of modeling.

### DETAILED DESIGN OF 1st LEVEL

The building entities representation is based upon two basic conceptual classes: the nodes and the arcs. In fact, because of the duality arc-node, only one entity will be used, a "node" or an "arc", according to the case. This entity is called "**Element of Network**" (**ENET**). An ENET will be a node if it is of a "mass" type and an arc if it is of "energy" type. An ENET of "energy" type (arc) has always an "upstream" and a "downstream" ENET.

The modeling is completed by the addition of two complementary entities: the "**material**" and the "**table**". The "material" is a constituent that has a unique list of thermo-physical properties. The "table" is an entity that allows to define the variation law of a variable. This law can be a piecewise constant or linear function for which the values are coded internally or stored in a file. For this modeling, each data of the building is potentially a variable. But practically, only certain ones are.

A material is uniquely associated to an ENET of a "mass" type, while a "table" can be, a priori, associated to any variable of the modeling.

The ENET is difficult to access for the user, and a working entity was joined to the modeling: the "Typical-Object". This entity brings together a certain number of ENETs, permitting their manipulation by blocks. Moreover, it contains a certain amount of information relative to all the ENETs that constitute it.

These "Typical-Objects" are classified in two categories: those which have a spatial existence (volume, walls and windows) and those that act by power injection (regulators and internal loads). From a conceptual point of view, this distinction has no reason to exist, but it allows to limit the number of input windows.

Figure 2 gives an example of a wall and of internal loads.

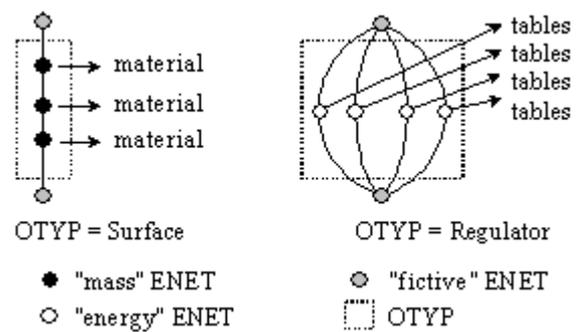


Figure 2: Examples of OTYP

The final ENETs of a "Typical-Object" are called "fictive" and serve uniquely to link the "Typical-Objects" together.

Remark: actually, the ENETs of a "Typical-Object" are predefined. A possible future evolution will allow the user to create and to access the ENETs of a "Typical-Object" in order to make his own models based upon the polymorph entity, which is the ENET. This will be accessible only to **CODYBA's** developers, which will be in charge of verifying that the introduction of any combination of these "atomic" models in the global network would not noticeably modify the calculation algorithms performances.

In practice, the four predefined entities exist under the form of classes and they inherit from the same class, the "Graphical-Object" which must assure their visibility:

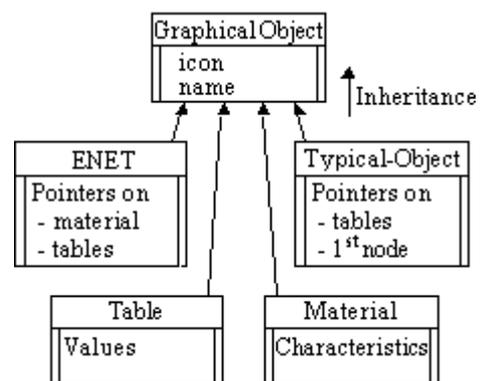


Figure 3: Modeling classes

The use of polymorphism, (a property of object-oriented languages) is very interesting in our case because this allows the use of only one entity. All the other one are derived from the primary one.

Thus a study associated to the building equivalent to a single list is composed of heterogeneous objects (see figures 4 and 7):

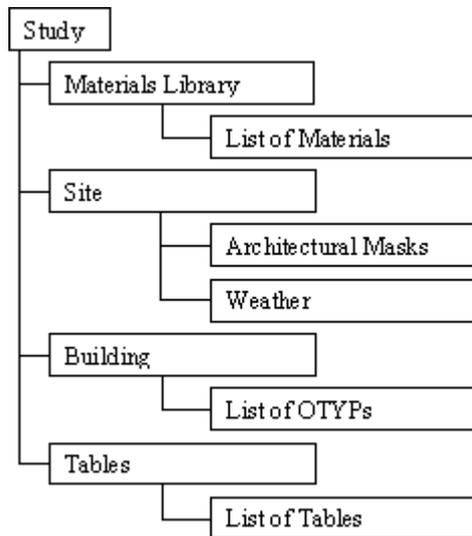


Figure 4: Objects list of a study

### DETAILED DESIGN OF 2nd LEVEL

1<sup>st</sup> level organisation is not general enough to be used by a simple algorithm.

A new "valued" graph is used now to compose with Blocks (node) and Links (arcs), which inherit both the abstract entity "calculation". From block entities a hierarchy of classes is defined to represent the various entities of calculation.

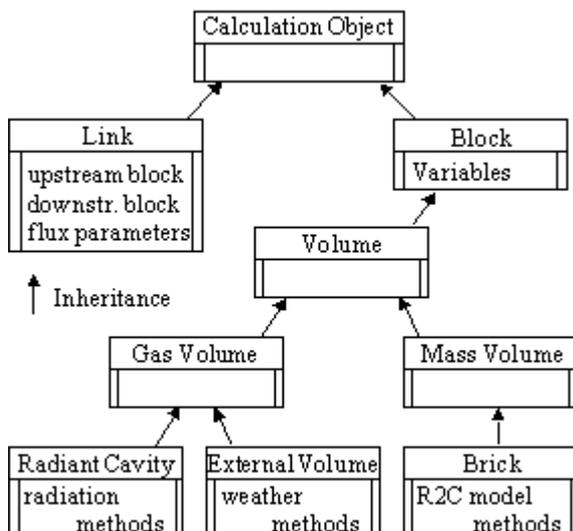


Figure 5: Hierarchy of calculation classes

The main data for "Block" are its list of variables, for "Links" the upstream Block and the downstream Block. All those data are needed to calculate the F flow at each time step.

Two lists of objects are obtained: Blocks and Links. The calculation algorithm is written simply in overlaps of loop on elements of list.

First, the time integration method is the implicit Jacobi algorithm for matrix sub-system resolution, mixed with a "ping-pong" to insure convergence of the global equation system.

On the other hand, the Jacobi method is no good to solve a thermal problem involving ventilation because of non-linearities (which is in contradiction with the item 4 of our specifications). Nevertheless, in a first stage, the non-linear system (flows F of the arcs depend on the values of the variables of the Blocks) can be solved by the Jacobi method using given values of flows F (previous iteration values for example). In a second stage, the values of F flows are corrected by an adapted heuristic method, until convergence. Preliminary tests seem to show that that goes rather well.

### CONCEPTION SUMMARIZE

The general architecture is described in figure 6:

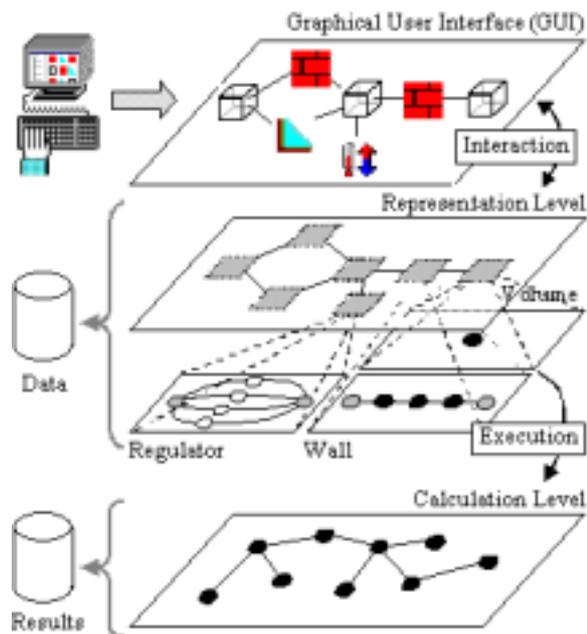


Figure 6: Overview of building modeling

The kernel is composed of the representation level and the calculation level: CODYBA can be thus compared with a black box receiving commands and executing them.

It should be noted that in this architecture, the graphic interface is not necessary. It is possible to replace it only by reading of a file, with or without transformation of the data. One presents in conclusion the openings towards other tools.

## EXAMPLES OF SCREENS

The "building's description" main screen contains two elements of the toolboxes of development tools. On left side appears element of type "TreeView" and on the right side, an element of the "ListView" type (see figure 7). The first makes it possible to manage a tree structure and the second manages elements presented in a list form.

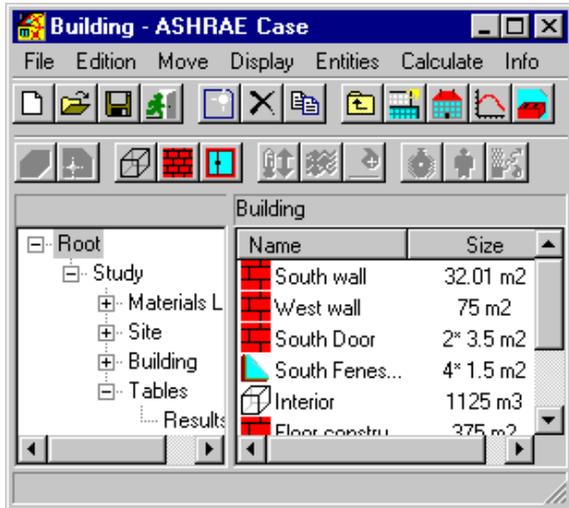


Figure 7: "Icono-graphical" project's description

The building is presented under a hierarchical form according to usual ergonomics in modern exploring software. Each entity is accessible by its icon for the edition operations. The drag-and-drop technique facilitates the introduction of a component from the libraries.

Navigating in the headings of TreeView, one reaches quickly the various elements of the study (here the list of different controllers being in the "interior" zone).

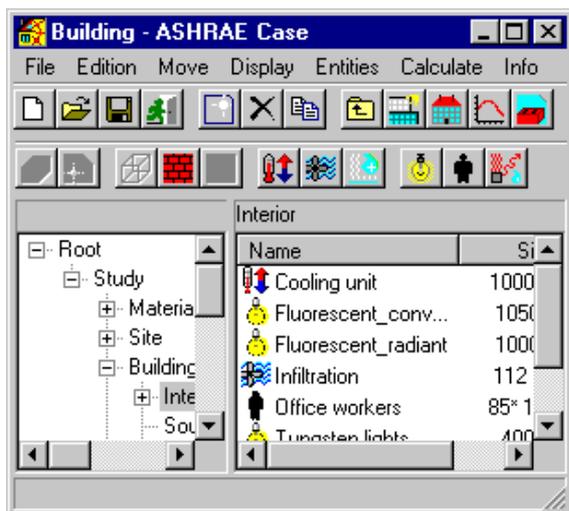


Figure 8: Regulators and internal loads

As an example of "Typical-Objects", figure 9 presents the screen for a temperature regulator.

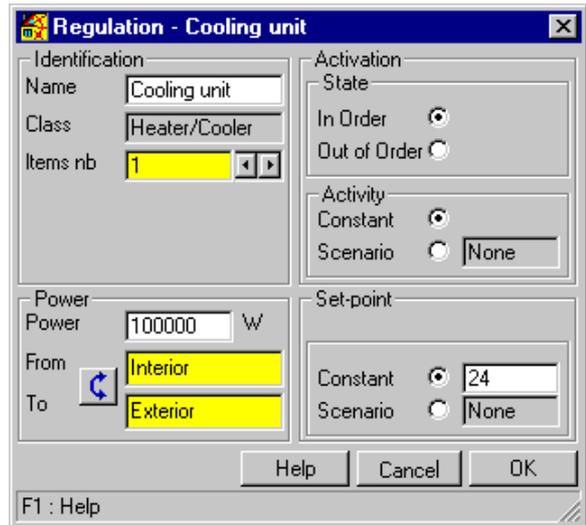


Figure 9: Typical screen for a heating device

The "activity" and "set-point" variables can have scenarios: in this case tables are associated to the heating device.

## VALIDATION CASE

For the integration tests, analytical solutions were used as primarily cases. The "BESTEST" comparisons [8] will be undertaken as soon as possible. However, a classical mono-zone case will be present now [5][9].

The definition of a daily evolution is needed in order to have the sensible cooling load to assure a given temperature in a one-story commercial building (figure 10), located in the eastern United States near 40°N latitude.

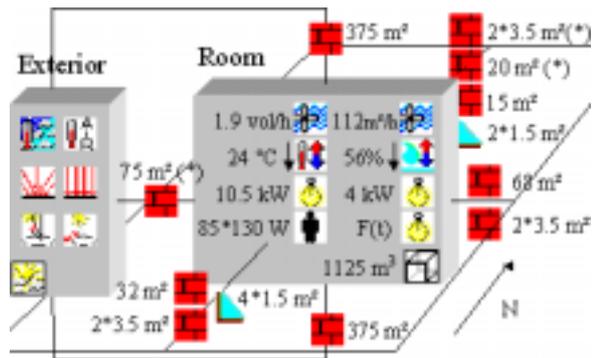


Figure 10: Example of application

Adjacent buildings on the North and West façades are not conditioned, and the air temperature within them is approximately equal to the outdoor temperature at any time of day (star marked data).

Simulation is performed for the 21<sup>st</sup> of July. The summer outdoor and indoor conditions are: dry bulb 35°C, daily range 11°C, wet bulb 25°C, specific humidity 0.0159 kg (vapour)/kg (dry air), respectively dry bulb 24°C, wet bulb 18°C, specific

humidity 0.0104 kg(vapour)/kg(dry air). The site ground reflectance is 0.2.

The control parameters are: step number of 60 minutes, 5 days for the initialisation.

The examples of data are presented next, including only those that are not shown in figure 10 like building elements (Table 1), materials (Table 2), convective exchange coefficients (Table 3), regulators and internal loads (Tables 4 and 5), weather data (Table 6).

Table 1: Building elements utilised in the example

Entity Name	Number * Surface (m <sup>2</sup> )	Layer (mm) / Material	Int. / Ext. Absorption (%)
North Interior door	2* 3.5	13 Finish 25 Wood	44/ 44
North adjoining wall	20	200 Common brick 100 Face brick	88/ 88
North Outside wall	15	20 Plaster/gypsum 200 Heavy concrete block	88/ 44
North Fenestration	2*1.5	3 Plate glass 3 Plate glass	--
East wall	68	20 Plaster/gypsum 200 Heavy concrete block	88/ 44
East door	2* 3.5	13 Finish 25 Wood	44/ 44
South wall	32	20 Plaster/gypsum 200 Common brick 100 Face brick	88/ 44
South door	2* 3.5	13 Finish 25 Wood	44/ 44
South Fenestration	4* 1.5	3 Plate glass 3 Plate glass	--
West wall	75	200 Common brick 100 Face brick	88/ 88
Floor	375	100 Heavy concrete block	88/ --
Roof	375	100 Low density concrete 2 Steel siding 51 Rigid insulation 10 Felt & membrane 12 Slag or stone	88/ 88

The windows have no mask and are in the external facade face. They have a U-Factor of 4.6 W/m<sup>2</sup>.K and are 55 % glazed. Layers are given from interior to

exterior. The floor lies on a perfectly insulated ground: heat exchange are neglected ([9] p 26.7). The ceiling receives solar radiation.

Table 2: Materials used in the example

Material	$\lambda$ (W/m.K)	$\rho$ (kg/m <sup>3</sup> )	Cp (J/kg.K)
Air	0.026	1.2	1007
Slag or stone	1.436	1670	881
Steel siding	45	7689	920
Low density concrete	0.173	641	840
Finish	0.415	1249	1090
Wood	0.121	593	2510
Plate glass	1.15	840	2700
Felt & membrane	0.19	1121	1670
Rigid insulation	0.043	32	840
Heavy concrete block	1.038	977	840
Common brick	0.727	1922	840
Plaster/gypsum	0.727	1602	840
Face brick	1.333	2002	920

Transmission and absorption coefficient of glazes are 0.85 and 0.08 respectively

Table 3: Convective exchange coefficients

Convective Exchange Coefficients (W/m <sup>2</sup> .K)	Floor	Wall	Ceiling
Interior	1	4.09	6.1
Exterior	11.7	11.7	15

The exchange coefficients of the walls are CODYBA's default one. The utilised radiative exchange coefficient is equal to 5 W/m<sup>2</sup>.K.

Tungsten lamps are continuously light on with constant power, concerning fluorescent lamps the following scenario ([9], p26.36, line 40 and line 35) is used:

Table 4: Power of fluorescent lights

hour	Rad./Conv. (W)	hour	Power (W)
0-1	3825 / 0	12-13	5031 / 10500
1-2	3554 / 0	13-14	5413 / 10500
2-3	3305 / 0	14-15	5770 / 10500
3-4	3074 / 0	15-16	6101 / 10500
4-5	2859 / 0	16-17	6409 / 10500
5-6	2659 / 0	17-18	6695 / 10500
6-7	2473 / 0	18-19	5911 / 0
7-8	2299 / 0	19-20	5498 / 0
8-9	3189 / 10500	20-21	5113 / 0
9-10	3700 / 10500	21-22	4755 / 0
10-11	4176 / 10500	22-23	4422 / 0
11-12	4619 / 10500	23-24	4112 / 0

The fluorescent lamps are thus represented by two distinct equipments ("fluorescent radiative" and "fluorescent convective"). Other equipments are described in Table 5.

Table 5: Regulators and internal loads

Entity Name	Activity	Nominal / Set point	Remarks
Tungsten lights	S	4 kW --	conv/lwr/swr: 20/40/40 %
Fluorescent radiative	P	10 kW --	lwr/swr: 50/50 %
Fluorescent convective	P	10.5 kW --	conv: 100 %, from 8h to 18h
Cooling unit	S	100 kW 24 °C	--
Deshumidification	S	100 kW 56 %	--
Infiltration	P	112 m3/h --	2.8m <sup>3</sup> /h/person /passage for 10 persons/h from 8h to 18h
Ventilation	S	1.9 ach/h --	--
Office workers	P	75 W sensible 55 W latent	conv/lwr/swr: 67/33/0 % from 8h to 18h

lwr-long wave radiation, swr-short wave radiation, conv-convective. S-steady activity, P-profile activity.

Table 6: Weather data

h	Ta (°C)	DHF (W/m <sup>2</sup> )	dHF (W/m <sup>2</sup> )	A (deg)	H (deg)	RH (%)	Tsk (°C)
1	25.4	0	0	-151	78.5	0	25.4
2	24.9	0	0	-145	80.8	0	24.9
3	24.4	0	0	-136	83.3	0	24.4
4	24.1	0	0	-126	84.8	0	24.1
5	24	0	1	-117	85.3	4.2	24
6	24.2	66.5	33.5	-108	84.3	14.8	24.2
7	24.8	221.5	56.5	-99.7	81.3	26	24.8
8	25.8	388.5	70.5	-90.7	76.6	37.4	25.8
9	27.2	532	79	-80.2	70.6	48.8	27.2
10	28.8	644	85	-65.8	64.3	59.8	28.8
11	30.7	714	88	-41.9	57.6	69.2	30.7
12	32.5	737	89	0	52.1	73.4	32.5
13	33.8	714	88	41.9	48.4	69.2	33.8
14	34.7	644	85	65.8	46.0	59.8	34.7
15	35	532	79	80.2	45.3	48.8	35
16	34.7	388.5	70.5	90.7	46.0	37.4	34.7
17	33.9	221.5	56.5	99.7	48.1	26	33.9
18	32.7	66.5	33.5	108	51.5	14.8	32.7
19	31.3	0	1	117	55.7	4.2	31.3
20	29.8	0	0	127	60.7	0	29.8
21	28.6	0	0	136	65.0	0	28.6
22	27.5	0	0	145	69.3	0	27.5
23	26.6	0	0	151	73.19	0	26.6
24	26	0	0	-153	75.7	0	26

h, Ta, DHF, dHF, A, H, RH et Tsk are respectively: solar time, external air temperature, direct solar flux on an horizontal plane and diffuse solar flux, solar azimuth and height angles, relative humidity, sky temperature.

The obtained "CODYBA" results are represented in figure 11 and table 7 and compared to those presented in the "ASHRAE HANDBOOK FUNDAMENTALS" [9] for the same example. The utilised methods by ASHRAE are the transfer functions method ([9] p 26.36, line 52), "ASHRAE TFM", and a method of "total equivalent temperature differential values and a system of time-averaging" ([9] p 26.60, line 52), "ASHRAE TETD/TA".

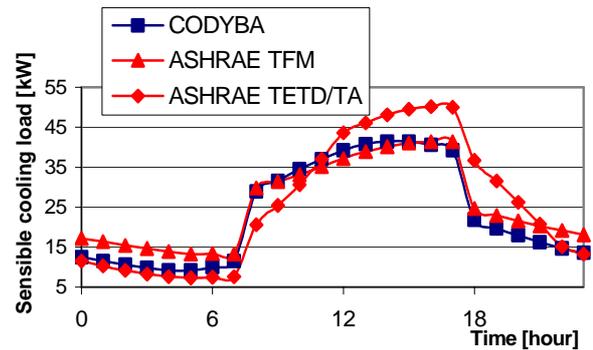


Figure 11: Sensible cooling loads

As it can be remarked, CODYBA results are situated between those given by the two ASHRAE methods. Moreover, all the peaks for the sensible cooling loads are obtained at the same hour. The peak values obtained using the ASHRAE methods have 20% of difference between them. The maximum sensible cooling loads for CODYBA method is given below, as well as for the ASHRAE methods (Table 7):

Table 7: Maximum sensible cooling loads

Maximum cooling load	CODYBA	ASHRAE "TFM"	ASHRAE "TETD/TA"
	41468 W	39712 W	50096 W

The simulation time is less than 1 s with a 260 MHz Pentium II.

## RELEASE

Version 6 of CODYBA is used intensively in academic institute and in some engineering and design departments. It has been diffused in 15 issues since April 2000. The 6.3 demonstration version is available for free with french or english or brazilian portuguese menus as specify in point 8 of our specifications.

## LINKS WITH OTHER TOOLS

In the present version, CODYBA is essentially a calculation tool for which the interface is well adapted to the treatment of buildings represented by a few zones. Concerning the treatment of more complex buildings (more than a dozen zones), CODYBA's interface is not well adapted because of the great amount of necessary data. An other way to get them is necessary.

That does not call into question the CODYBA's calculation algorithms, which are not limited by the great number of elements describing the building. It is simply a question of supplementing the existing interface by another channel: a neutral commands language.

Currently this language exists in a prototype form, used in a software link between CODYBA and type 56 of "TRNSYS" [1]. This links also "SimCAD" CAD tool [10][11], developed by CSTB (french scientific and technique center for buidings).

## CONCLUSIONS

Current version of CODYBA reached a good degree of maturity. Work is now directed to the development of the user interface (upstream and downstream), primarily by coupling CODYBA with existing tools.

The objective is to have a language to manage data flows. The most important thing is to communicate with external applications in order to concentrate efforts on the calculation algorithms by leaving to the ergonomic specialists the realization of input-output interfaces.

The authors will gratefully accept the applications for the trials of this software.

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